Lesson 1: Appearances and Anatomy

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Learning objective for lesson 1: Students will learn about the diversity in dinosaur appearances, both bony and soft tissue structures, and will be able to identify major features of the major groups of dinosaurs.

Welcome to Dino 101! In this course you will explore the anatomy, ecology, and evolution of one of the grandest and most fascinating animal groups to ever walk the earth. The study of dinosaurs is a subdivision of the branch of science known as palaeontology. **Palaeontology** is the study of all prehistoric life. A palaeontologist's knowledge of prehistoric life comes primarily from fossils. A **fossil** is any preserved evidence left behind by a prehistoric organism. The word fossil literally means "dug up", and fossils are usually objects or structures found buried in ancient rock formations. Dinosaur fossils include footprints, eggshells, coprolites (fossil poop), and in rare instances even skin and feather impressions. However, most dinosaur fossils are bones. Bones are partially made of minerals, which do not decay as easily as flesh and other soft tissues. For this reason, bones have a much greater chance of being preserved as fossils, and a dinosaur palaeontologist needs to know a great deal about bones.

Learning objective 1.1: Describe sizes of dinosaurs by comparing modern organisms to dinosaurs

Although the most well known dinosaurs tend to be enormous, multi-ton animals, dinosaurs actually came in a wide variety of sizes. Although birds are the smallest dinosaurs that we know of, we still have many examples outside this group of living dinosaurs that were no larger than a house cat. For example, the small dinosaurs *Microraptor* and *Fruitadens* were probably less than a metre long as adults, and weighed less than a kilogram. One possible reason people may think dinosaurs are larger than they are is because they are often "inflated" in pop culture. For example, many people know of the large, predatory *Velociraptor* from the Jurasic Park franchise. However, in reality *Velociraptor* was about the size of a dog or a turkey, not a human. Some of the biggest dinosaurs were truly enormous though. Many of the long-necked sauropod dinosaurs were bigger than any land animal today, and the only living animals that come close to them in size are whales.

Learning objective 1.2: Identify major bones and bone types in dinosaur skeletons

Adaptations are traits that have evolved because they serve specific functions. Bones are adaptations that help animals to survive by serving four major functions. First, bones passively resist gravity and maintain an animal's

form. When you stand up straight, the bones in your legs act like support columns. Your leg bones support your weight, without your muscles needing to actively flex and expend energy. Second, bones provide a ridged framework for muscle attachment. Raise your right hand high over your head. When you do, you can feel muscles in your shoulder flexing. The bones in your shoulder girdle provide a solid anchor against which your shoulder muscles can pull, and long bones in your arm allow it to move as single stiff unit. Third, bones provide protection and can also be major components of horns and other robust weapons. For example, your skull bones form a natural helmet that protects your brain -- a delicate organ that could be seriously damaged by an impact with an unexpectedly low doorway or rogue baseball. Finally, bones store mineral reserves. Often the resources that an animal needs to grow and develop are plentiful at one time and rare at another. During times of plenty, animals may store a valuable mineral resource, such as calcium, by growing a new bone deposit or by increasing the density of already existing bone. Later, during a time when the resource is scarce, the animal may gain access to stored minerals by reabsorbing some of its bone.

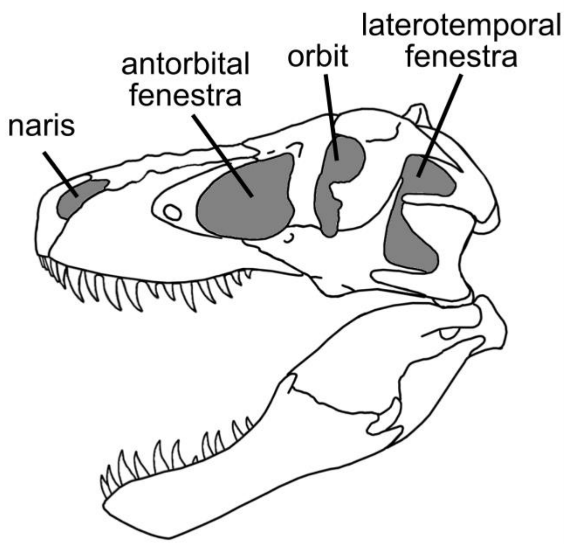
Dinosaurs belong to a group of animals known as vertebrates (and so do you). **Vertebrates** are animals that have two special kinds of skeletal adaptations: skulls and vertebrae. **Vertebrae** (singular: vertebra) are structures made primarily of bone and/or cartilage that surround a portion of the spinal nerve cord. Together, vertebrae interlock with each other in a series and form the **vertebral column**. Fish, amphibians, turtles, snakes, birds, and mammals are all examples of vertebrates. The first vertebrates were aquatic animals that evolved over 500 million years ago. Animals that lack vertebrae are called **invertebrates**, and include animals like insects, spiders, snails, squids, clams, jellyfish, and worms. Since the origin of animal life, there have always been many more species of invertebrates than vertebrates. However, vertebrates are more numerous when it comes to species of large animals, especially on land. This success is probably related to the vertebral column's ability to passively support weight and to anchor enlarged muscles.

Skulls and Jaws

The skull is not a single bone. Rather, the skull is made up of many bones that are tightly locked together. More than any other part of the skeleton, a skull can give a palaeontologist great insight into a dinosaur's life. The upper and lower jaws may contain teeth and/or include a beak, and they are critical for interpreting what a dinosaur was adapted to eat. The rear portion of the skull includes the brain case. The **brain case** is a hollow chamber formed by multiple skull bones that houses the brain. There are many small openings into the brain case. Nerves pass through these opening and connect to the brain. The size and shape of a brain case can indicate the size and shape of the brain that it housed, and, therefore, can provide clues to a dinosaur's mental capabilities.

Dinosaur skulls also have multiple pairs of large openings. The **nares** (singular: naris) are the pair of openings for the nostrils. The **orbits** are the pair of openings for the eyes. In some animals, like turtles, there are no other large skull openings, but dinosaurs have several. These additional skull openings are called **fenestrae**. The word "fenestrae" (singular: fenestra) is Latin for "windows". Behind each orbit, dinosaurs have two fenestrae: the

fenestrae on the lateral sides of the skull are called the **laterotemporal fenestrae** and the fenestrae on the top of the skull are called the **supratemporal fenestrae**. Both the laterotemporal fenestrae and the supratemporal fenestrae provide extra room for large jaw muscles. Between each orbit and naris, dinosaurs have a third fenestrae pair, called the **antorbital fenestrae**. The function of the antorbital fenestra is unclear. They may have simply been adaptations that made dinosaurs skulls lighter, or they may have also housed large sinus cavities that helped warm the air that dinosaurs breathed.



Tyrannosaurs rex skull showing different fenestrae. Original image by Scott Hartman, modified by M. Vavrek.

The Axial Skeleton

The vertebral column, or spinal column, is comprised of a series of interlocking vertebrae that begins with the first vertebra in the neck and ends with the last vertebra in the tail. Nearly all vertebrae share a basic form. A vertebra has a spool- or disk-shaped body, called the **centrum**. Above the centrum is the **neural arch**, which covers the neural canal. The **neural canal** is the opening in each vertebra, through which the spinal nerves run. A vertebra may also have processes extending from the centrum or neural arch. **Vertebral processes** provide attachment surfaces for muscles and sometimes provide articulation surfaces for ribs. Two common types of vertebral processes are **transverse processes**, which extend from the lateral sides of the vertebrae, and **spinous processes**, which extend upwards from the neural arch.

Throughout the vertebral column of any animal, the shapes of individual vertebrae vary. In many animals, like most fish, this variation in vertebral shape is slight. However, in animals like dinosaurs and mammals, vertebrae in different regions of the vertebral column have strikingly different shapes. Vertebrae in the neck are called **cervical vertebrae**. Cervical vertebrae often have extra-large openings for blood and nerve channels and are adapted to support the weight of an animal's head. Vertebrae in the back are called **dorsal vertebrae**. Dorsal vertebrae often have tall spinous processes and large rib articulation surfaces. Vertebrae in the hips are called **sacral vertebrae**. Because the pelvic bones in terrestrial vertebrates serve as solid anchors for powerful leg muscles, the pelvic bones (later discussed in detail) are fused to the sacral vertebrae. To further increase the strength of the hips, the sacral vertebrae are also fused with one another and form a single solid bone structure called the **sacrum**. Finally, vertebrae in the tail are called **caudal vertebrae**. Underneath caudal vertebrae are bones called **chevrons**. Chevrons protect a large blood and nerve channel and provide support for tail muscles.

In dinosaurs, cervical, dorsal, sacral and caudal vertebrae may all support ribs (although, in the tail, ribs are usually only present at the base and are tightly fused to vertebrae). The largest ribs are those that connect to the dorsal vertebrae and form the ribcage. In dinosaurs, all dorsal vertebrae connect with ribs; however, in mammals, the dorsal vertebrae close to the hips do not. Also unlike mammals, some dinosaurs had gastralia, or “belly ribs”. **Gastralia** are small ribs positioned across a dinosaur’s underbelly, underneath the ribcage.

The Appendicular Skeleton

Dinosaurs, mammals, reptiles, and amphibians all belong to a special group of vertebrates known as tetrapods. “Tetrapod” means “four feet”. **Tetrapods** are animals that evolved from an ancient ancestor with four feet and four limbs. Most tetrapods still have four feet and limbs, although some, like humans, have hands instead of front feet and some, like snakes, have lost their limbs altogether.

The limbs of a tetrapod are connected to the rest of the skeleton by **limb girdles**. The forelimbs connect to the **pectoral girdle**, also called the shoulder girdle. The **scapula**, or shoulder blade, is the largest bone in each side of the pectoral girdle. The hindlimbs connect to the **pelvic girdle**, or hip bones. Each side of the pelvic girdle is composed of three bones that tightly connected to one another. The upper hip bone is called the **ilium**. It is to the ilium that the sacral vertebrae are fused. Below the ilium are the **pubis** and the **ischium**. The pubis is positioned in front of the ischium, nearer the belly, and the ischium is positioned behind the pubis, nearer the tail. The **acetabulum** is the depression or (as in dinosaurs) the hole in the pelvic girdle into which the hind limb articulates.

Between the shoulder and elbow is the largest bone in the forelimb, called the **humerus**. Between the elbow and the wrist are two parallel bones, called the **radius** and **ulna**. In most tetrapods, the radius is the thinner of the two. The bones in the wrist are called **carpals**. The bones between the wrist and fingers are called **metacarpals**. Finger bones are called **phalanges**. The arrangement of bones in the hindlimbs is very similar to that in the forelimbs. Between the hip and knee is the largest bone in the hindlimbs, called the **femur**. Between the knee and the ankle are two parallel bones, called the **fibula** and **tibia**. The tibia is the bone that forms our shin. If you've ever broken a bone in your leg or ankle, there's a good chance that you broke your fibula, which is the thinner or the two lower leg bones. The bones in the ankle are called tarsals. The bones between the ankle and toes are called **metatarsals**. Finally, the bones in the toes are called **phalanges** (the same name as the bones in the fingers).

The same pattern of bones in the limbs is shared by nearly all tetrapods. Changes in the proportions of the limbs, or in the proportions of particular limb bones, or in limb posture can have a major impact on how a tetrapod moves. For instance, when we human stand and walk, our heels touch the ground. When dinosaurs stood and walked, only their toes touched the ground. The metatarsals of dinosaurs (which are located in the flat of our feet) were tilted upwards and contributed to the length of a dinosaur’s leg. This helped dinosaurs to take longer steps and probably allowed many species of dinosaurs to run much faster than humans can.

Learning objective 1.3: Identify the two major types of pelves in dinosaurs.

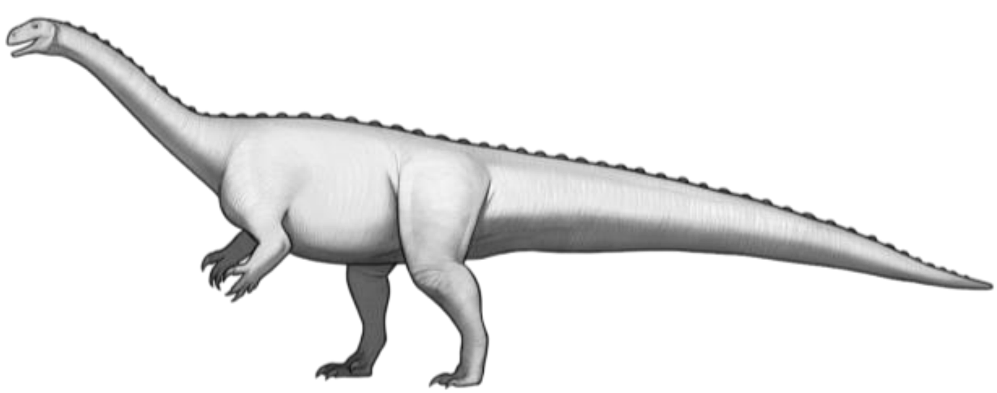
Skeletal differences and similarities are used to sort dinosaurs into groups. There are two major groups of dinosaurs: saurischians and ornithischians. Within each of these two major groups there are many smaller groups. **Saurischian** dinosaurs are those that share an evolutionary ancestor that had a pubis that extended downwards and forwards, towards the ribcage. **Ornithischian** dinosaurs are those that share an evolutionary ancestor that had both a special beak-forming bone in the upper jaw (called the predentary) and a pubis that extended downwards and backwards, towards the tail.

Be careful. "Saurischian" and "ornithischian" are basic and very old terms, but they can be confusing. "Saurischian" means "lizard hipped", and "ornithischian" means "bird hipped". These terms were used because in a lizard's hips the pubis extends downwards and forwards and in a bird's hip the pubis extends downwards and backwards. Remember, these groups are based on the pubis shape of a shared ancestor. The groups were named before it was recognized that birds are living dinosaurs. While some dinosaurs still have the same pubis shape as their ancestor, others have changed it. For instance, despite being the namesake of term "ornithischian", birds are not ornithischians -- birds are not "bird-hipped" dinosaurs! Birds are part of a special group of saurischian dinosaurs that changed their pubis from extending forward to extending backwards (unrelated to the similar hip shape of the ancestor of ornithischian dinosaurs). Here is another potential complication: saurischians and ornithischians share a common ancestor with each other, and palaeontologists are not sure what this ancestor was like, whether it had more ornithischian or saurischian traits, or some mosaic of the two.

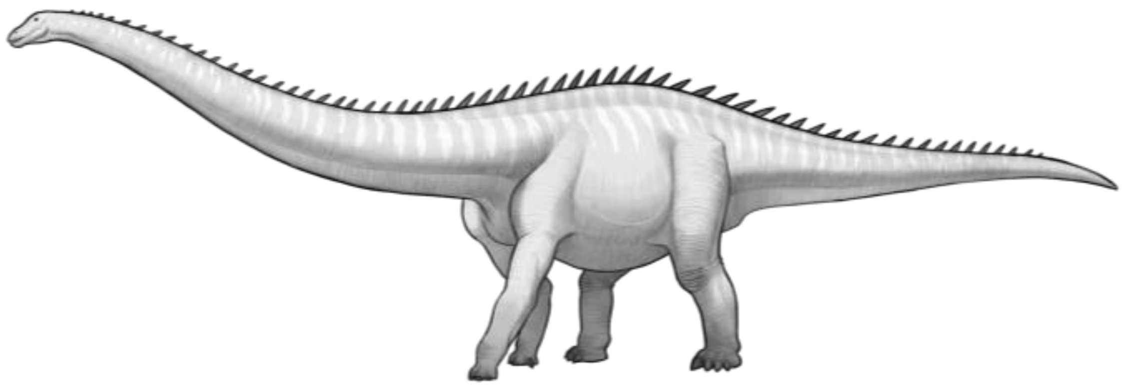
Learning objective 1.4: Identify the major bony features of general dinosaur groups.

Saurischians

There are two major groups of saurischian dinosaurs: sauropodomorphs and theropods. **Sauropomorphs** were large herbivores with elongated necks and relatively small heads. **Prosauropods** were an early group of sauropodomorphs and were the first group of large-bodied herbivorous dinosaurs to evolve.



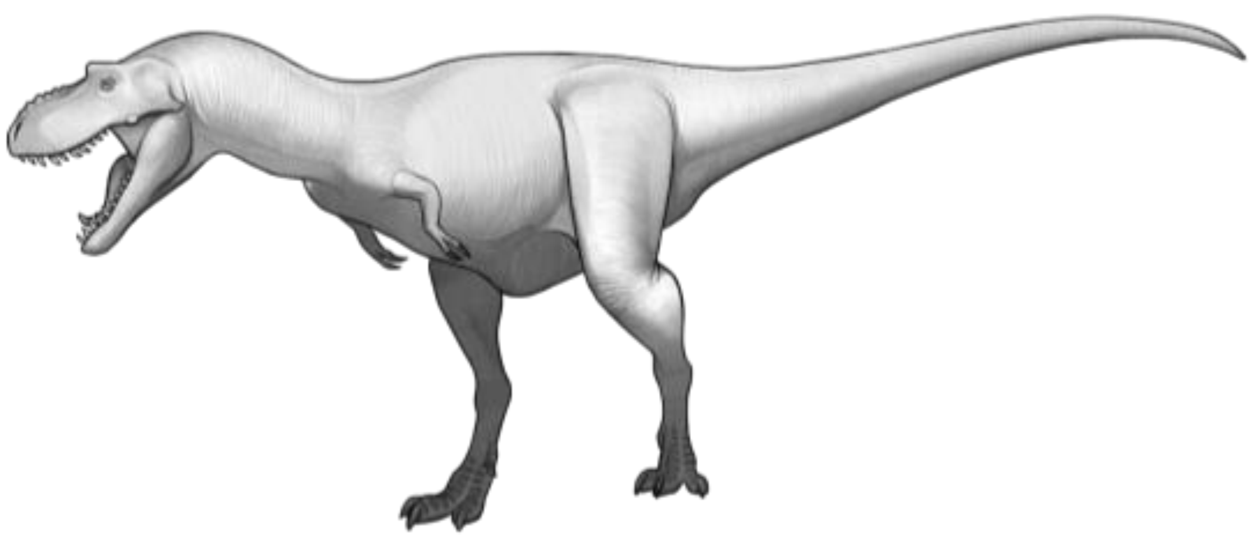
Massospondylus by Joy Ang



Diplodocus by Joy Ang

Sauropods were a later group of sauropodomorphs. Many sauropods attained truly gigantic size, and the group includes the largest animals to ever walk the earth. Sauropods stood on four robust and column-like legs. Sauropod vertebrae (particularly the cervical vertebrae) are filled with complex air sacks, which helped to reduce weight. The teeth of sauropods are usually simple and peg-like.

Theropods were bipedal saurischian dinosaurs that shared a carnivorous ancestor. Many theropods were carnivorous and have serrated blade-like teeth and sharp hooked claws, but some were herbivorous and a few lack teeth altogether. Birds are a kind of theropod, making theropods the only group of dinosaurs that is not completely extinct.



Gorgosaurus by Joy Ang.

Ornithischians

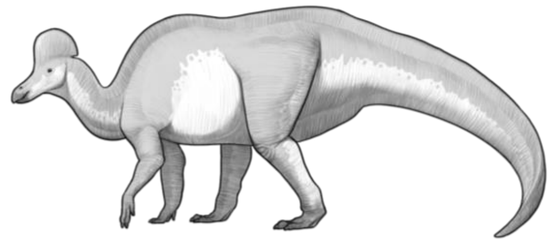
The backwards extending pubis, which gives ornithischians their name, was an adaptation that created more space in the ribcage. This extra space was probably filled by extra-large digestive organs. Plant matter is much harder to

digest than meat, and most herbivores need larger stomachs and intestines than do carnivores. All known ornithischian dinosaurs are thought to have been primarily herbivorous. The beaks, which all ornithischians possess, are also herbivorous adaptations that helped ornithischians to chop off large mouthfuls of vegetation. There are five major groups within the ornithischians: ornithopods, pachycephalosaurs, ceratopsians, stegosaurs, and ankylosaurs.

Ornithopods include a wide range of dinosaurs that lack armor and that either walked bipedally all the time or assumed a bipedal stance when running. Many ornithopods are small antelope-sized dinosaurs, but some, like the iguanodonts and hadrosaurs, grew to be multi-ton giants. **Iguanodonts** are large ornithopods with a spike-shaped claw on each hand.

Iguanodon by Joy Ang

Another group of large ornithopods, **hadrosaurs,** are the famous "duckbilled dinosaurs". Hadrosaurs evolved late in the history of dinosaurs, but were highly successful. Some hadrosaurs have elaborate boney crests, and all hadrosaurs have strikingly large beaks in the front of their mouths and dense, tightly packed rows of small teeth in the rear of their mouths. Together, these teeth form large chewing surfaces and are collectively referred to as **dental batteries**.



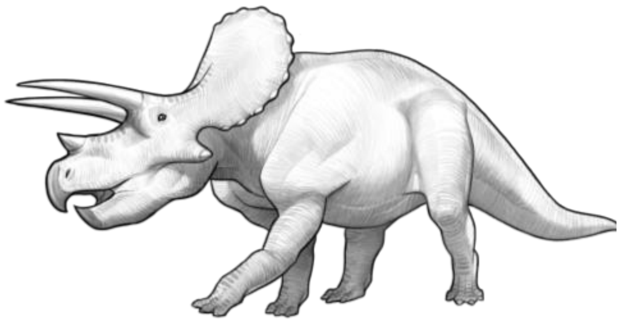
Corythosaurus by Joy Ang

Pachycephalosaurs were bipedal with short arms, unusually stout and strong tails, and armored skulls. Some pachycephalosaurs have thick, domed skull roofs and backwards-pointing horns. The function of pachycephalosaur skull armor will later be discussed in detail, but it has long been speculated that pachycephalosaurs may have rammed predators or have butted heads with each other in competitions for territory or mating rights. Pachycephalosaurs have sharp conical teeth in the front of their mouths, behind their beaks, and leaf-shaped teeth in the rear. These front teeth have led some palaeontologists to hypothesize that pachycephalosaurs might have been omnivores (adapted to eat meat as well as plants).

Pachycephalosaurus by Joy Ang

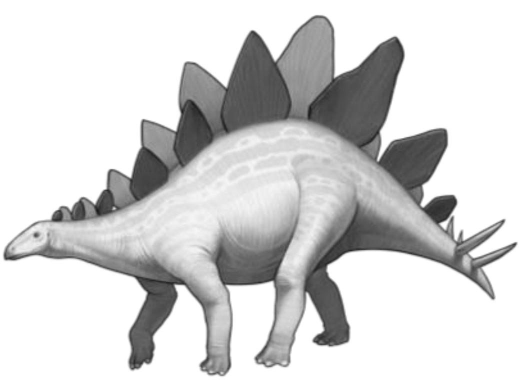
Ceratopsians are another group that evolved late in the history of dinosaurs. Ceratopsians have large parrot-like beaks and skulls that are greatly expanded in the rear. In most ceratopsians, this rear skull expansion is taken to an extreme and a large boney frill, or neck

shield, is present. Many ceratopsians have large horns and also possess dental batteries. *Triceratops* is easily the most famous of the ceratopsians and is one of the largest. Most large ceratopsians were quadrupedal and have short tails.



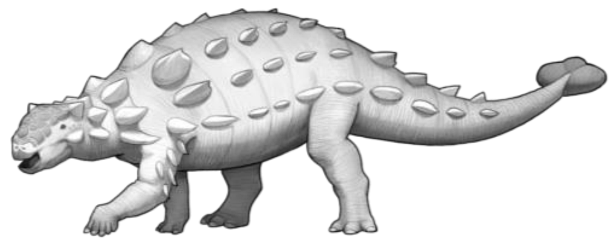
Triceratops by Joy Ang

Stegosaurs are a group of quadrupedal dinosaurs with rows of projecting osteoderm plates down their backs and long osteoderm spikes on their tails. **Osteoderms** are bones that develop within the skin and are a common component of animal armor. Some stegosaurs also have osteoderm spikes on their backs and over their shoulders. Stegosaur front limbs are much shorter than their hind limbs. Stegosaurs were probably not fast runners, but they could probably pivot quickly and could rear up and stand on their hind legs. Stegosaur heads are small relative to their bodies and their snouts are narrow.



Stegosaurus by Joy Ang

Ankylosaurs are the most heavily armored of all dinosaurs. Ankylosaurs are quadrupedal with short legs and wide ribcages. The backs and skulls of most ankylosaurs are covered in spikey protective osteoderms. Some anklosaurs also have large osteoderms on the ends of their tails, forming a mace or “tail club”. Unlike their relatives, the stegosaurs, most ankylosaurs have short snouts and broader, rounded beaks.



Anodontosaurus by Joy Ang

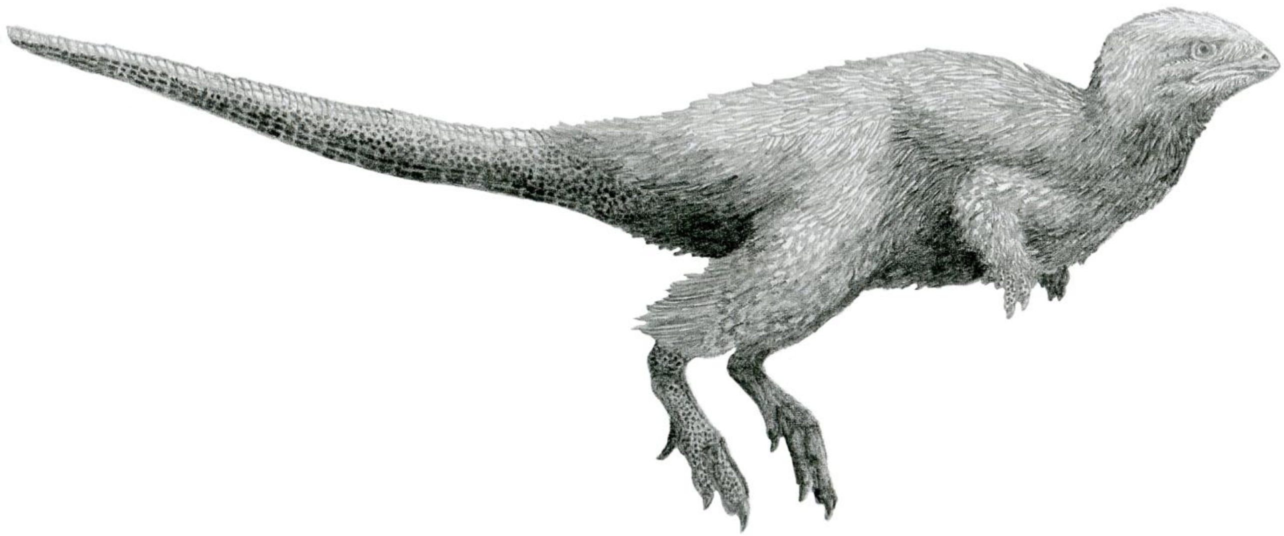
Learning objective 1.5: Discuss the soft tissues of dinosaurs.

As has already been discussed, bones are the most common dinosaur fossils because bones decay less rapidly than do softer tissues. This makes it difficult to know what a dinosaur’s **integument** (body covering) was like. However, under exceptional circumstances softer tissues can be fossilized. Fossil footprints are natural foot molds that were originally made in soft, fine-grained sediments. Sometimes, a footprint may include more than just the rough outline of a dinosaur’s foot and may have impressions of foot scales. Skin impressions from other regions of a dinosaur’s body can be preserved if a dinosaur was covered by mud shortly after it died and before its flesh rotted away. Direct fossilization of skin and other soft parts is also possible, but such instances are exceedingly rare.

Dinosaur specimens that include a lot of skin fossils are often called “mummies”. The first mummified dinosaurs were hadrosaur specimens, found in Wyoming in 1910. These revealed that hadrosaurs were covered with scales and that scales from different regions of the body often had different shapes. Fossil scales are also known from specimens of theropods, sauropods, ceratopsians, stegosaurs, and ankylosaurs. The scaly skin of dinosaurs has a slightly better chance of being fossilized than would our own skin, because scales are coved by a substance called keratin. **Keratin** is a tough but flexible material that also composes hair, feathers, fingernails, and the outside of claws, beaks, and horns.

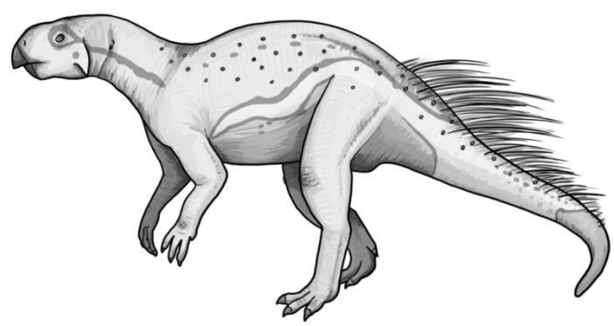
A major breakthrough in the study of dinosaur integument came in 1996, when a small theropod specimen with fossil feathers was discovered in Liaoning, China. This little carnivorous dinosaur was called ***Sinosauropteryx***. The feathers had been preserved, because the dinosaur’s body was buried suddenly by extremely fine ash from a volcano. Since this first discovery of dinosaur feathers, many other have been made in Liaoning. We now know that lots of small theropods had a covering of simple hair-like feathers and some, like *Microraptor*, had feathered wings. In 2012, feathers were first reported from the large tyrannosauroid ***Yutyrannus***. At over a ton in weight, *Yutyrannus* is the largest known feathered dinosaur.

Yutyrannus copyright Lida Xing, used with permission.



Reconstruction of *Kulindadromeus*, a fluffy ornithischian dinosaur from Russia. Fossils show that *Kulindadromeus* had a variety of integumentary structures: thin, fluffy filaments on its neck and back, feather-like structures on its upper arms and legs, unusual ribbon-like structures on its lower legs, and more typical scales on the feet and tail. Art by Tom Parker and used under the CC-BY-SA 4.0 license.

Theropod dinosaurs had feathers and filamentous integument, but what about other dinosaurs? Could ornithischians have been fluffy as well? A few tantalizing specimens unearthed over the last few years have suggested that some ornithischians might also have had feather-like integument. A specimen of the early ceratopsian ***Psittacosaurus*** preserved unusual long, stiff, bristle-like structures on its tail, but it was unclear if these were related to the feathers of birds and theropods. In 2009, a very primitive ornithischian from China called ***Tianyulong*** was described, and this ornithischian was covered in long filaments over most of its body. The most exciting specimen, however, was just described in the summer of 2014. ***Kulindadromeus*** was an early and primitive ornithischian dinosaur from Russia, and it preserves not just simple, bristle-like filaments like those found in *Psittacosaurus* and *Tianyulong*, but branching, feather-like structures as well! It seems likely that many dinosaurs might have had some combination of scales, fluffy filaments or quills, and true feathers.

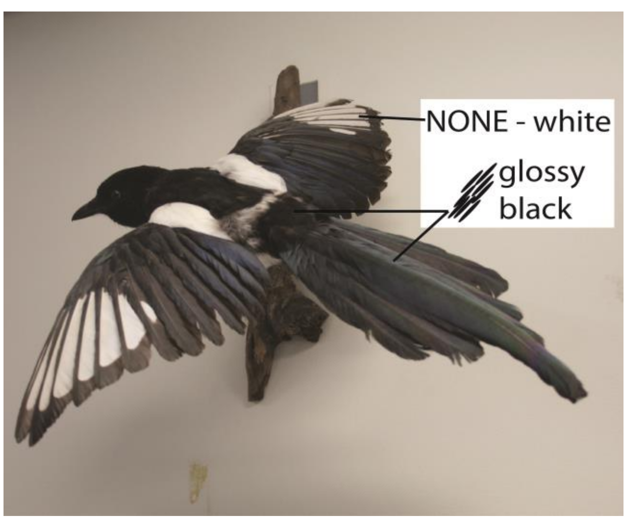


Psittacosaurus by Rachelle Bugeaud.

Recall that osteoderms are bones that develop within the skin, so these bones also count as integumentary structures. Osteoderms comprise the armor covering of many types of modern animals, including armadillos, crocodilians, and some lizards. Among dinosaurs, large osteoderms formed the plates

and spikes of stegosaurs and the armor and tail-club ends of ankylosaurs. Some sauropods also have osteoderms, although it has been hypothesized that the osteoderms of sauropods were less important for protection and more important as mineral reserves.

What color dinosaurs were has always been a mystery. Recently, a clever new approach has begun to try and solve this mystery, at least for some feathered dinosaurs. Feather colors are not directly preserved in fossilized feathers; however, studies of modern birds have shown that feather color is influenced by the shape and arrangement of **melanosomes** -- pigment cells within a feather. Under microscopic examination, melanosomes can be observed in some fossil feathers, and they give clues to a dinosaur's true colors. Black and gray colors result from long and narrow melanosomes. Brown and reddish colors come from short and wide melanosomes. White feathers have no melanosomes. Iridescence or 'glossiness', like the shiny black and blue feathers of crows and magpies, corresponds to narrow melanosomes that are aligned in the same direction.



Based on analyses of fossil melanosomes, it is thought that the dinosaur *Microraptor* was a glossy black, and the dinosaur *Anchiornis* is thought to have been black and white with some reddish-brown on its head.

Above: Bohemian waxwings (*Bombycilla garrulus*) in the University of Alberta Zoology Museum. Photo and diagram by V. Arbour.

Left: Black-billed magpie (*Pica hudsonia*) in the University of Alberta Zoology Museum. Photo and diagram by V. Arbour.

Anchiornis by Joy Ang, colourized by V. Arbour

Muscles are sophisticated tissues that produce force by contracting. Understanding dinosaur muscles is critical to understanding how dinosaurs moved. Unfortunately, muscles seldom fossilize. Recall, however, that one of the major functions of bones is to provide attachment surfaces and a rigid frame work for muscles. Consequently, the shapes of bones often correspond to particular muscle shapes, and muscles often leave behind scars on the surfaces of bones where they attached. Like the pattern of bones in the skeleton, the overall pattern of muscle arrangement is largely the same across all tetrapods.

Information about other soft tissues in dinosaurs is very scarce. One exceptional specimen of a small theropod dinosaur from Italy, called ***Scipionyx***, actually preserves the mineralized remains of the trachea (windpipe) in the throat, and the intestines. A red smudge in the front of the belly region might represent the decayed remains of the heart, liver, or spleen. Some of the muscles were also preserved, as were the keratinous sheaths over the claws.

Supplementary Materials

Laelaps: Biggest Dinosaur Ever? Maybe. Maybe Not. [Blog post]

Sauropod Vertebra Picture of the Week: Tutorial 15: the bones of the sauropod skeleton, Tutorial 15a: the bones of the theropod skeleton, and Tutorial 15c: the bones of the ornithischian skeleton. [Blog posts]

Dinosaur Tracking: The dinosaurs they are a-changin'. [Blog post]

Dinosaur Tracking: Dinosaur division is all in the hips. [Blog post]

Dinosaur Tracking: *Microraptor* was a glossy dinosaur. [Blog post]

Laelaps: Fluffy dinosaur raises questions over the origin of dinofuzz. [Blog post]. Plus, check out the high-resolution images of *Kulindadromeus* at Dave Hone's Archosaur Musings [Blog post].

Phenomena – Surprise! Well-studied dinosaur actually had a Cock's comb. [Blog post]. Plus, see how we studied this specimen in Peering inside a dinosaur mummy [Video].